SAS4321 Contemporary Quality Management System for Chemical Industry

Reliability

- Conceptualisation
- Quality
- Quality control and quality assurance
- Quality management system
- Process models
- Statistical process
- Process control tools
- Analytical tools – measurement process
- Inspection - sampling
- Acceptance
- Reliability

Definition

- Reliability is the probability that when a product is subject to certain prescribed(規定) operating conditions for its intended working life, it still performs satisfactorily.

Concepts

- Reliability has a value between 0 and 1 (i.e. probability).
- Provide a basis for comparing quality of different products or systems.
- For example, 0.99 means that 99 items out of 100 items of the product are still operating under the conditions specified.

Areas in reliability

- Reliability Measurement
- Reliability Prediction
- Reliability Engineering

Reliability measurement

- Failure rate
  i.e. measures the number of items failed in unit time (failure/hours)
- Mean Time to Failure (MTTF)
- Mean Time Between Failure (MTBF)
- Product Life Characteristic Curve
- Reliability Function

Reliability measurement

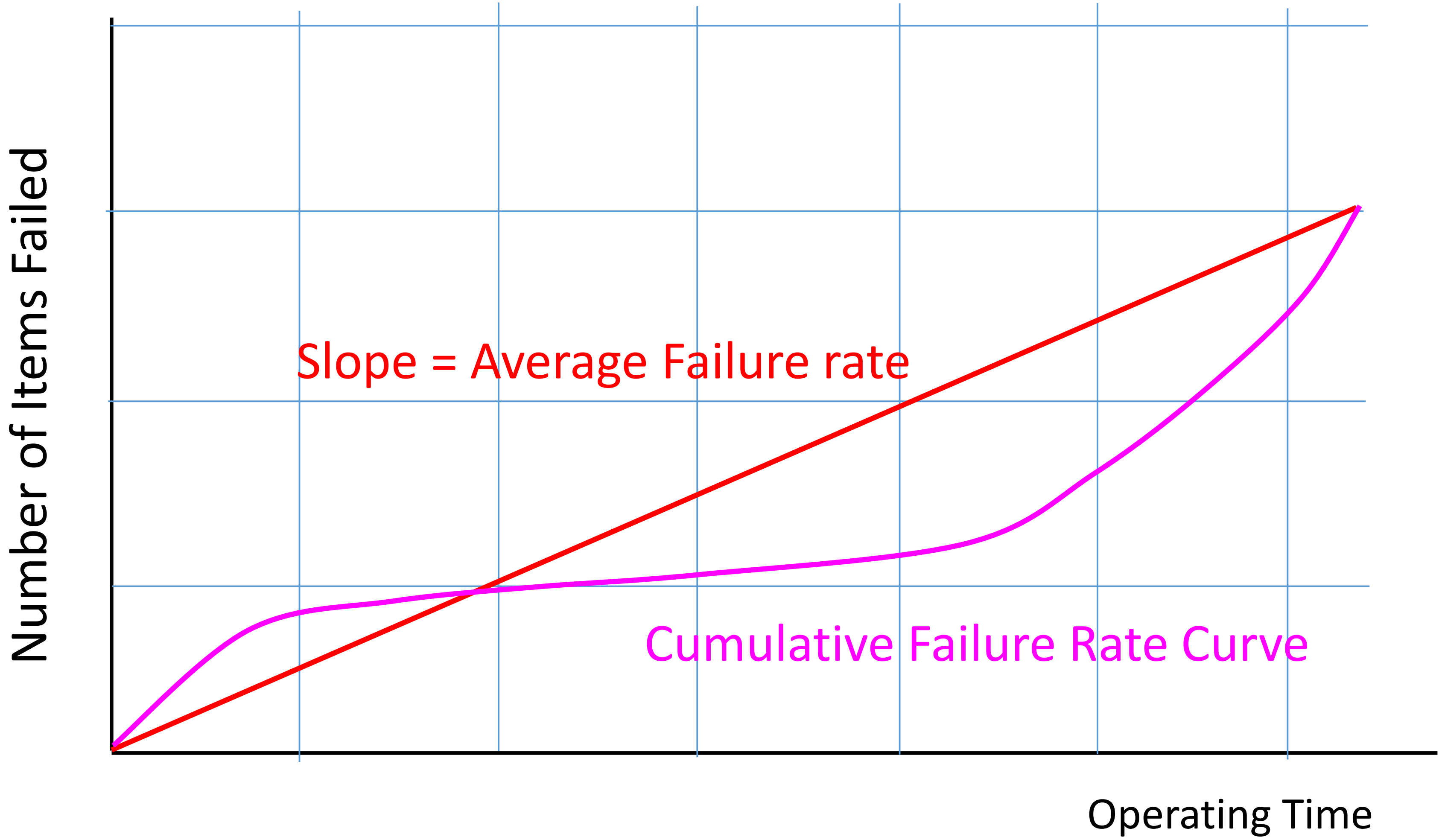


Figure Cumulative item failure vs time

Failure rate

$$\text{Failure Rate} = \lambda = \frac{\text{Number of items failed}}{\text{Total unit operating hours}}$$

$$\lambda = \frac{\text{Number of items failed}}{\text{Units Tested} \times \text{Number of hours tested}}$$

Unit: failure per hour or hour^{-1}

Example

- A reliability test is run for 10 items over a period of 5 days. Five items failed during the test at 5 hours, 30 hours, 65 hours, 70 hours and 100 hours. The remaining items lasted till the end of the test. What is the failure rate?

item	working hours
1	120
2	120
3	120
4	120
5	120
6	5
7	30
8	65
9	70
10	100
total	870

Example

Total operating time

= $(5 + 30 + 65 + 70 + 100 + 5 \text{ x } 120)$ hours

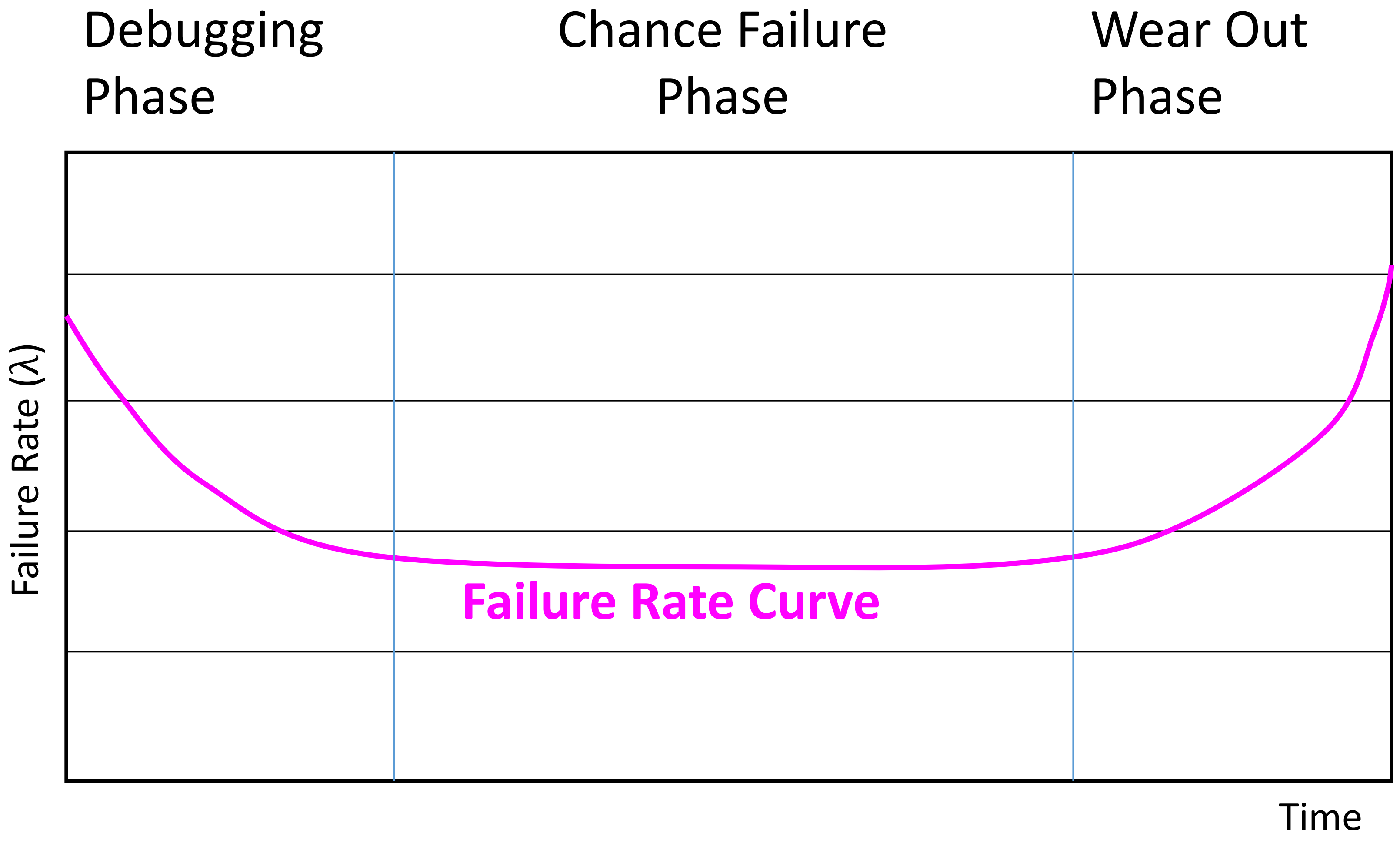
= 870 hours

Failure rate λ

= 5 failures / 870 hours

= 0.005747 failure per hour

Typical failure rate curve



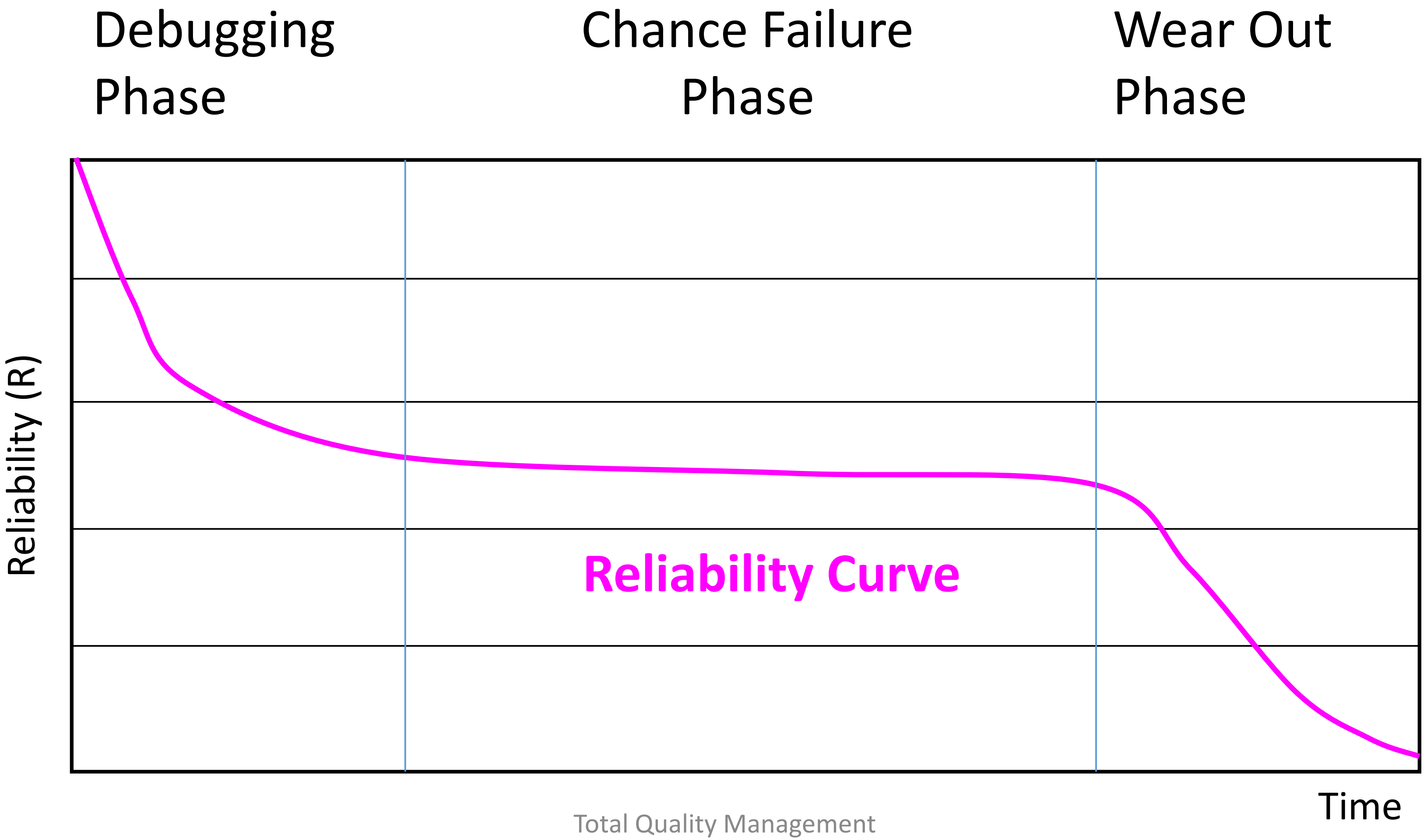
Typical failure rate curve

- Debugging Phase – Items with sub-quality component that is not rejected by the test procedure can fail early. This period is also called infant mortality period

- Chance Failure Phase – Items fail randomly due to operating stresses, usually cannot be predicted

- Wear Out Phase – Component aging and wear out are major causes of failure

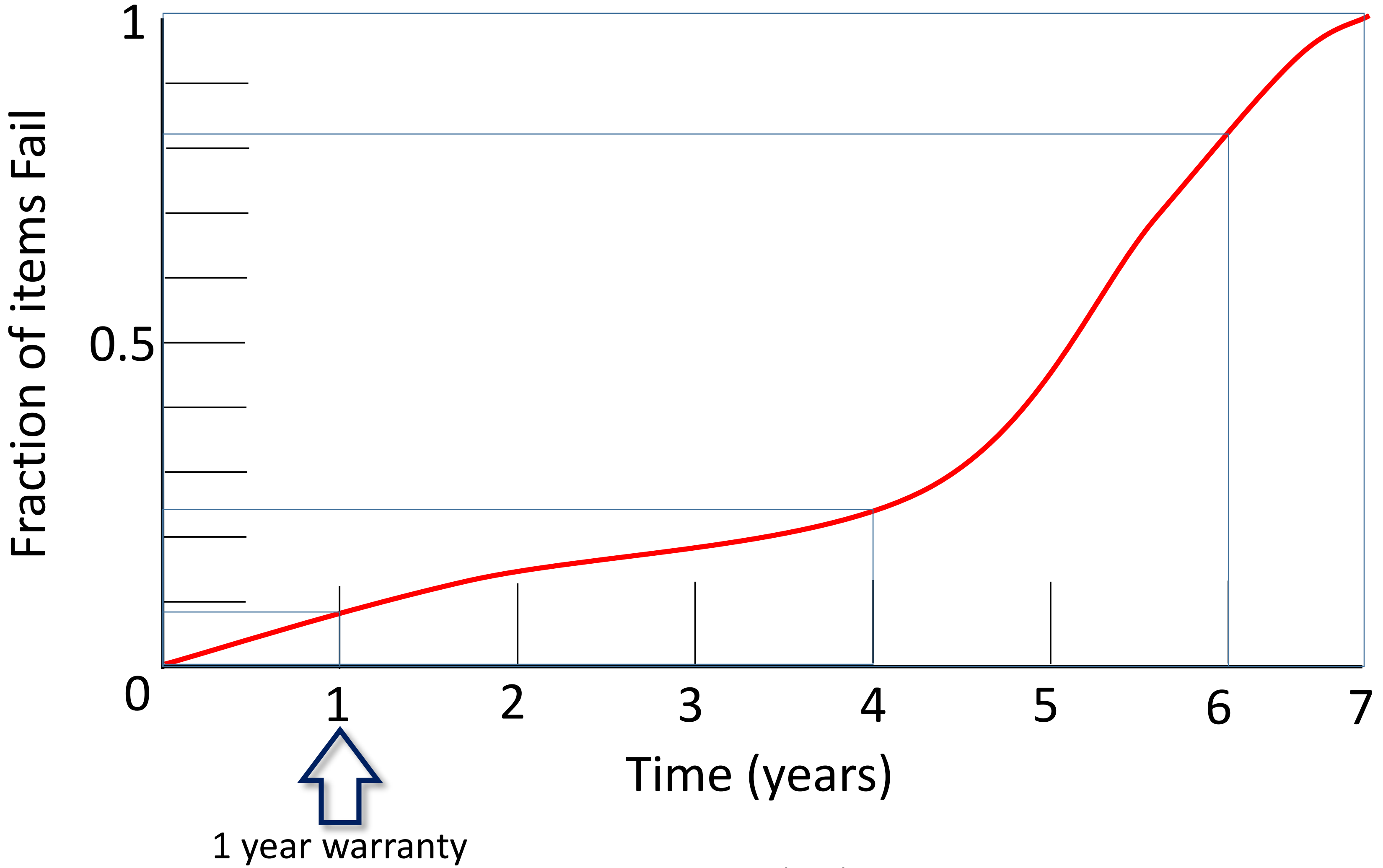
Typical reliability curve



Reliability curve

- Graph of Fraction Surviving vs Time
- Useful in Development of Warranties
- Useful in Scheduling of Maintenance Services

Reliability and warranty



Probability Distribution

Shape of distribution
β < 1 gamma
β = 1 exponential
β =2 Lognormal
β =3.5 normal

- In setting up warranty, the number of items fail within the warranty period can be determined from the cumulative failure curve.
- The cost of replacement or repair of these items can be calculated.
- Economic viability(可行性) can be determined from the replacement cost calculated.

- Exponential distribution
- $f(t) = \frac{1}{\theta}\left(e^{-\frac{t}{\theta}}\right)$

Weibull distribution

Shape of distribution

$$f(t) = \left(\frac{\beta}{\theta}\right)\left(\frac{t}{\theta}\right)^{\beta-1} e^{-\left(\frac{t}{\theta}\right)^{\beta}}$$

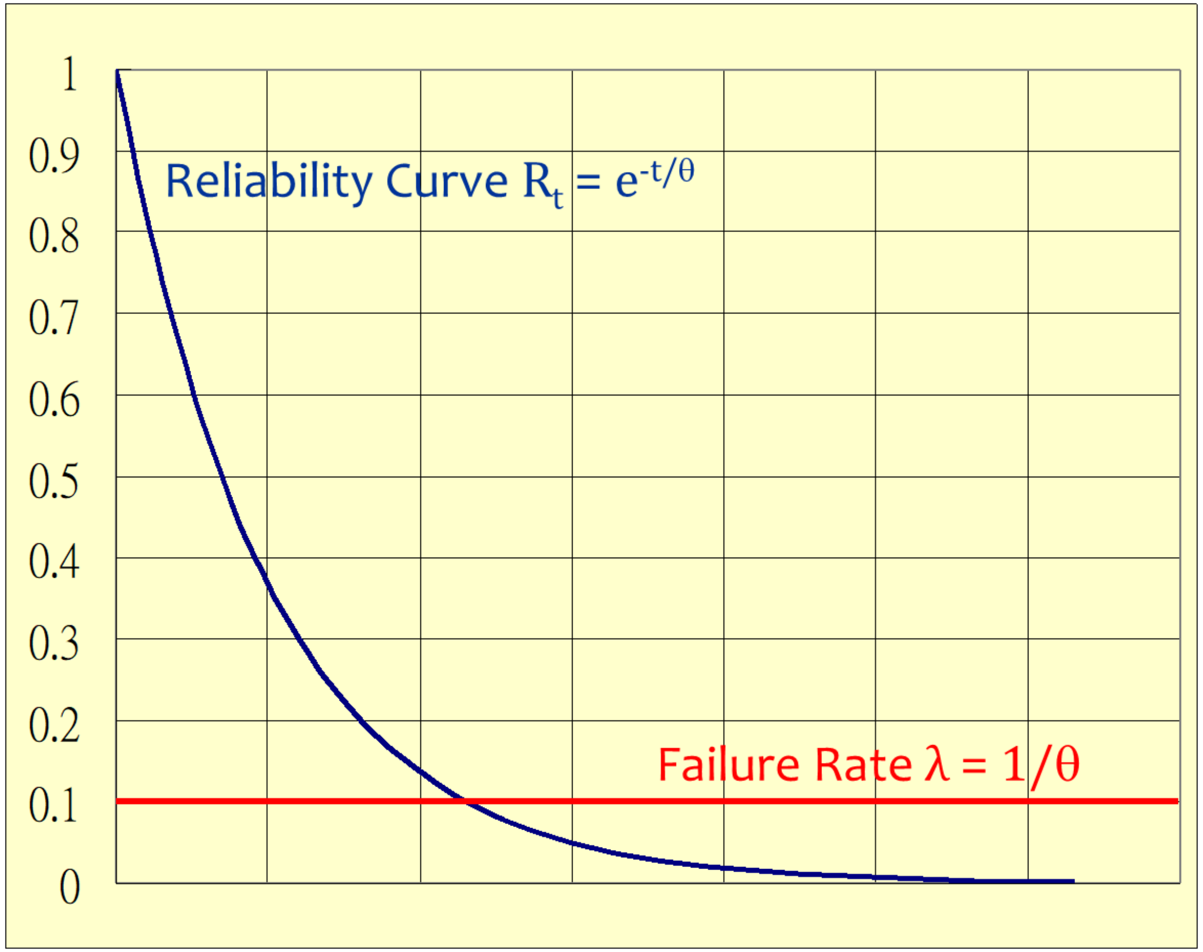
Reliability curve

- Exponential distribution
- $R(t) = e^{-\frac{t}{\theta}}$

- Weibull distribution
- $R(t) = e^{-\left(\frac{t}{\theta}\right)^{\beta}}$

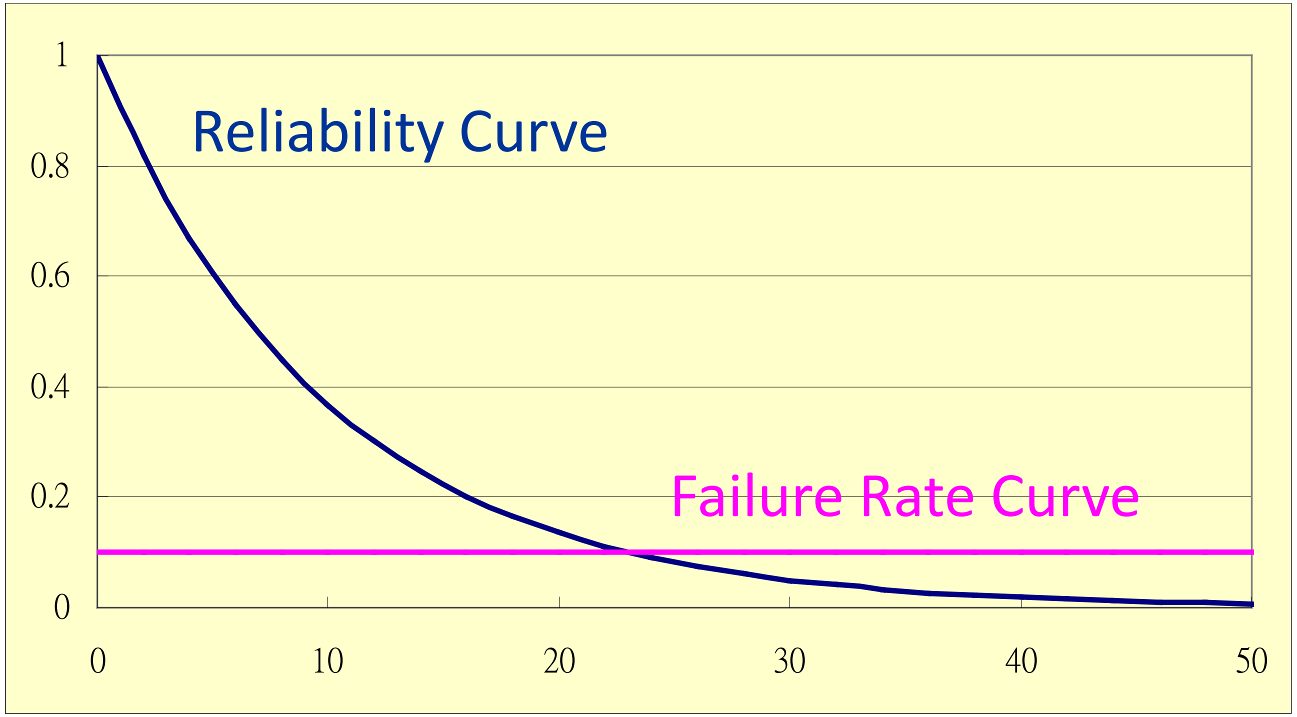
Common / Assumption

Failure rate curve (exponential)



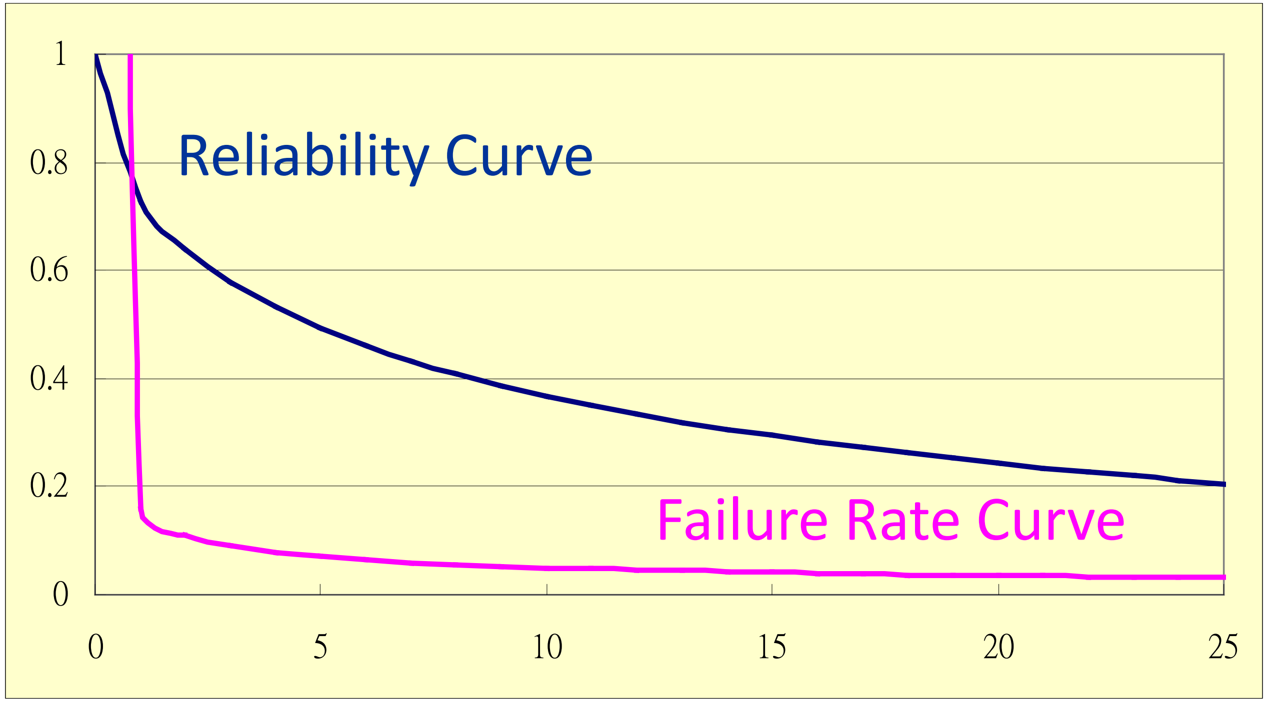
Failure rate curve (Weibull)

- $\beta = 1; \theta = 10$



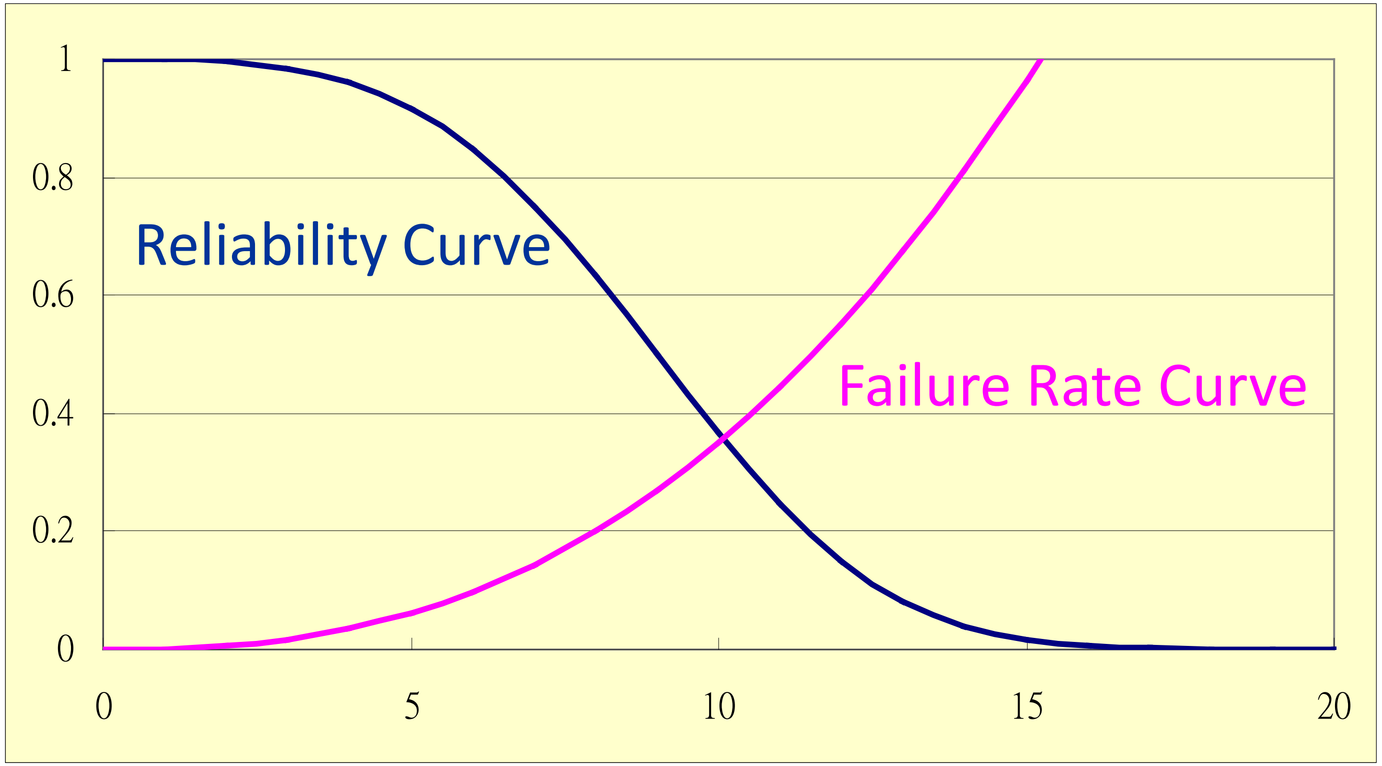
Failure rate curve (Weibull)

- $\beta = 0.5; \theta = 10$



Failure rate curve (Weibull)

- $\beta = 3.5; \theta = 10$



Failure rate curve

- Exponential distribution
- $\lambda = \frac{1}{\theta}$

- Weibull distribution
- $\lambda = \left(\frac{\beta}{\theta}\right)\left(\frac{t}{\theta}\right)^{\beta-1}$

Mean time to failure (MTTF)

- $\theta = \frac{1}{\lambda}$
- Average time before items fail
- For non-repairable items
- Reliable products last longer
- They are used to indicate how long products operate before failure occurred
- Unit: hour

Mean time between failure (MTBF)

- Also $\theta = \frac{1}{\lambda}$

- For repairable items

- The average time taken for failure to occur after the item is repaired

Example

- If the reliability of a product is 0.95 for 50 hours usage. Determine its MTTF. (Assume exponential distribution)

$$0.95 = e^{-\frac{50}{\theta}}$$

$\theta = 974$ hours

$\lambda = \frac{1}{974} = 0.001026$ failure per hour

Example

- The MTTF of a product is 1000 hours. What is the probability that the product will not fail in 2000 hours? (Assume exponential distribution)

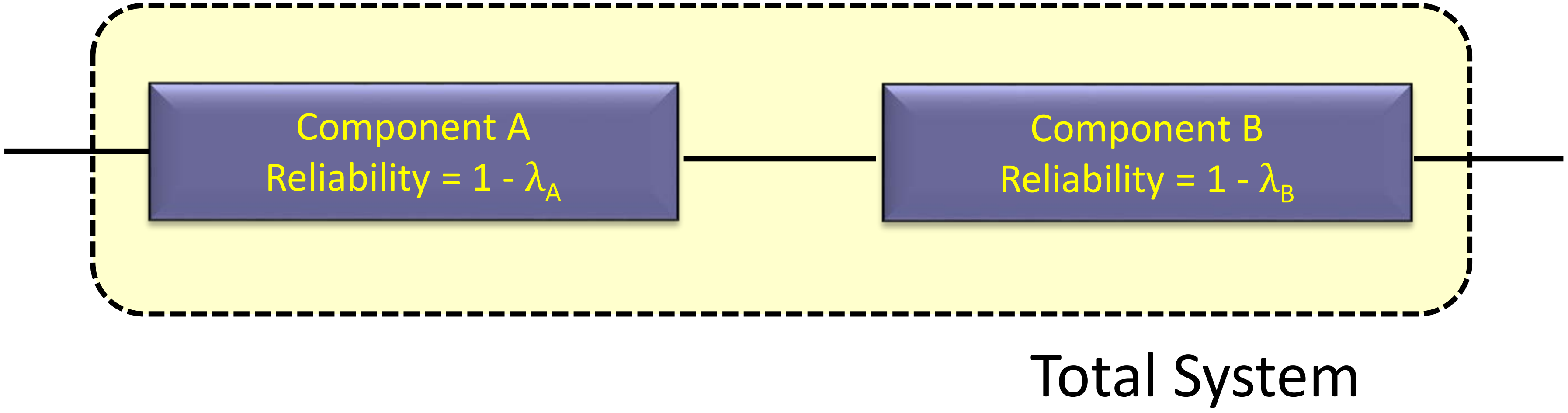
$$R(t) = e^{-\frac{t}{\theta}}$$

$$R(2000) = e^{-\frac{2000}{1000}} = 0.1353$$

Reliability of systems

- Systems are composed of components with known reliability
- Reliability of a system can be deduced from the reliability of individual components
- Components in Series
- Components in Parallel
- Series – Parallel System
- Stand-by components

Components in series



Components in series

- For the total system to operate, each component must be able to operate
- Probability of failure of the total system is higher than individual components
- If R_i denotes the reliability of i^{th} component

$$R_s = R_1 \times R_2 \times \cdots \times R_i \times \cdots \times R_n = \prod_{i=1}^{n} R_i$$

Components in series

- To improve system reliability for components in series
- Improve the reliability of individual components
- Reduce the number of components in the system

Example

- A system has 400 components arranged in series. If the reliability of each component is 0.999, what is the reliability of the system?

$$R_s = (0.999)^{400} = 0.6702$$

- What is the reliability of the system if the number of components is reduced to 100?

$$R_s = (0.999)^{100} = 0.9048$$

Components in series

- For reliability with exponential distribution

$$R_s = \left(e^{-\lambda_1 t}\right)\left(e^{-\lambda_2 t}\right)\cdots\left(e^{-\lambda_n t}\right)$$

$$= \exp\left[-\left(\sum_{i=1}^{n} \lambda_i\right) t\right]$$

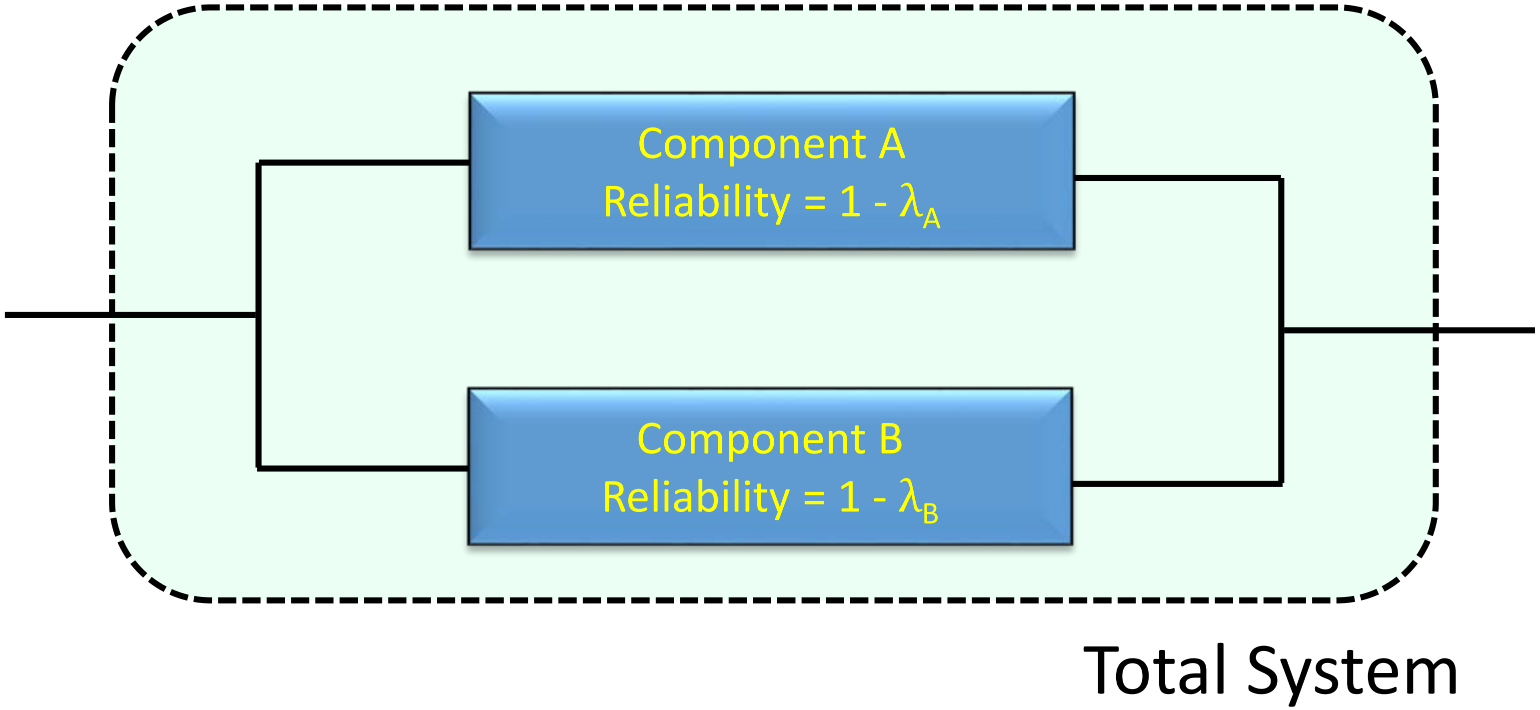
Components in series

$$\text{MTTF} = \frac{1}{\left[\sum_{i=1}^{n} \lambda_i\right]}$$

- If all components have the same reliability

$$\text{MTTF} = \frac{1}{n\lambda}$$

Components in parallel



Components in Parallel

- R_i denotes the reliability of ith component
- Probability of System Failure

$$F_s = \prod_{i=1}^{n} (1 - R_i)$$

- Reliability is

$$R_s = 1 - \prod_{i=1}^{n} (1 - R_i)$$

Example

- A system consist of 3 components arranged in parallel. If each component has reliability of 0.9, estimate the reliability of the system.

$$
\begin{aligned}
RS &= 1 – (1 – R_1)(1 – R_2)(1 – R_3) \\
&= 1 – (1 – 0.9)(1 – 0.9)(1 – 0.9) \\
&= 1 – 0.001 \\
&= 0.999
\end{aligned}
$$

Components in Parallel

- For reliability with exponential distribution

$$R_s = 1 - \prod_{i=1}^{n} \left(1 - e^{-\lambda_i t}\right)$$

- For components with equal reliability

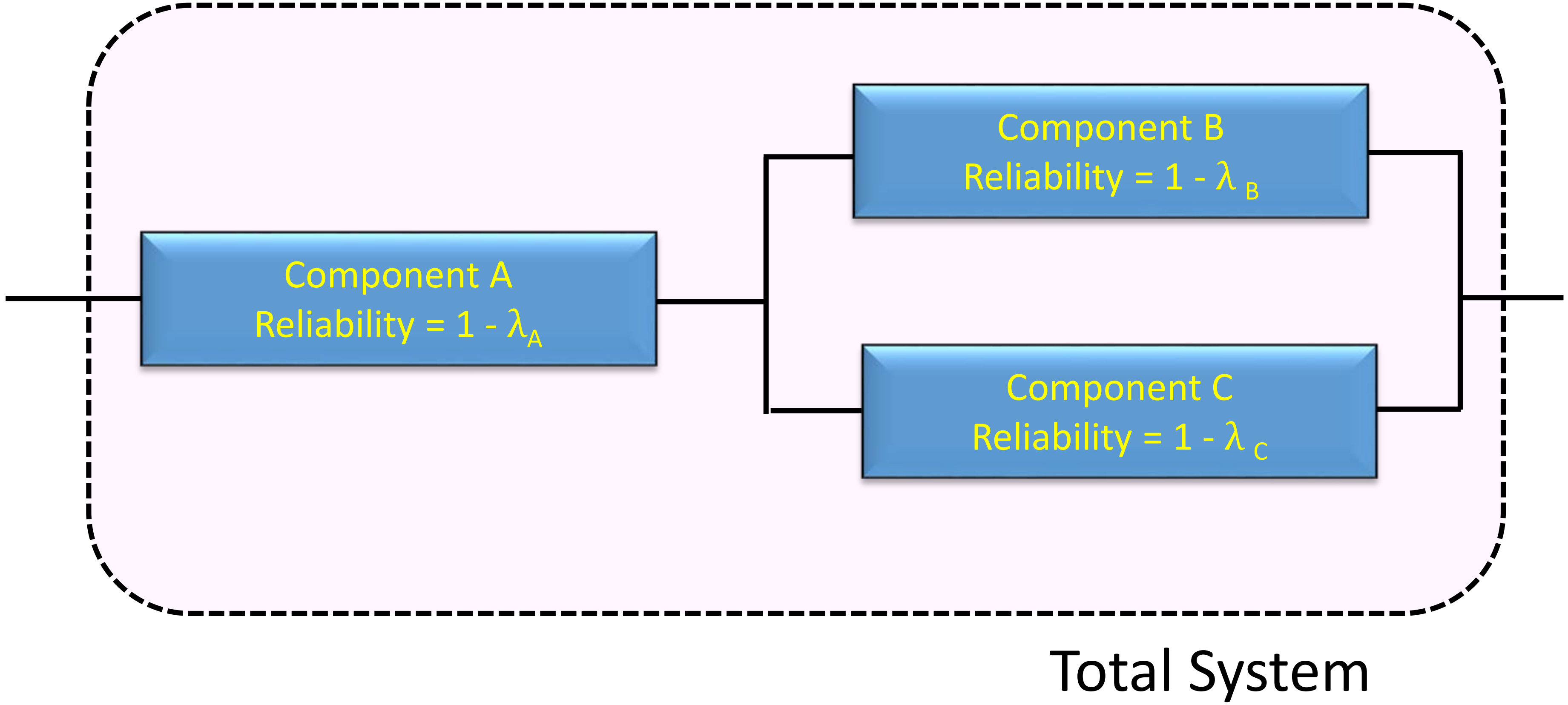
$$R_s = 1 - \left(1 - e^{-\lambda t}\right)^n$$

Components in Parallel

- The mean time to failure is given by

$$\mathrm{MTTF} = \frac{1}{\lambda}\left(1 + \frac{1}{2} + \frac{1}{3} + \cdots + \frac{1}{n}\right)$$

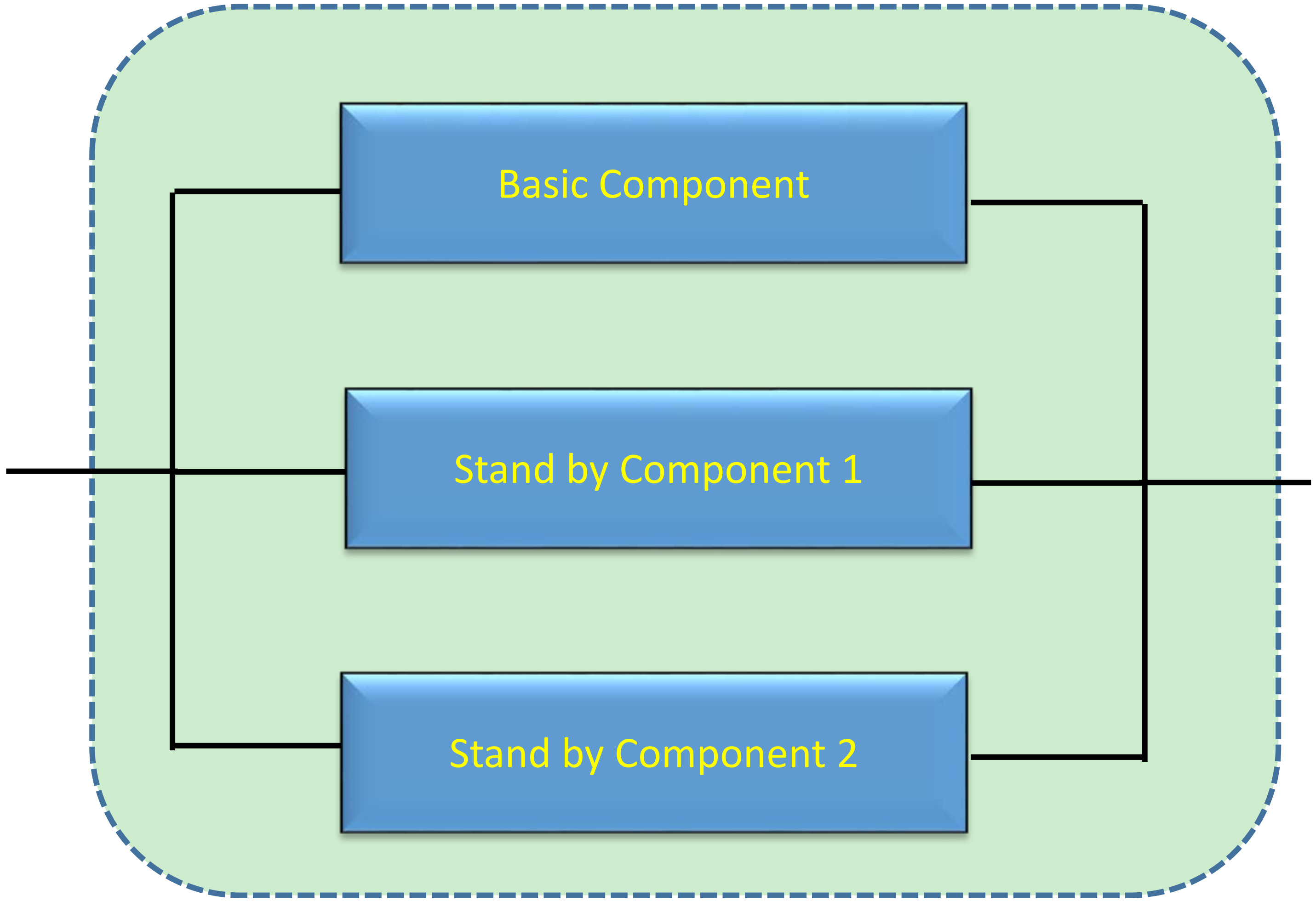
Series and parallel system



Series and parallel system

- Most system consist of components arrange both in series and parallel.
- Simplify the calculation by replacing parallel components with single component with same reliability.

System with stand-by component



System with stand-by component

- Stand-by component 1 will be operational only when the basic component fails.
- Stand-by component 2 will be operational only when the stand-by component 1 fails.

System with stand-by component

- Sensing equipment must be installed to trigger the operation of stand-by units.
- Higher reliability than system with parallel components.

System with stand-by component

- The probability of n failure in time t is given by the Poisson Distribution

$$P(n) = \frac{e^{-\lambda t}(\lambda t)^n}{n!}$$

- For system with basic unit only

$$R = e^{-\lambda t}$$

System with stand-by component

- For system with basic unit and one stand-by unit

$$R = e^{-\lambda t} + e^{-\lambda t}(\lambda t)$$

- For system with basic unit and two stand-by units

$$R = e^{-\lambda t} + e^{-\lambda t}(\lambda t) + \frac{e^{-\lambda t}(\lambda t)^2}{2!}$$

System with stand-by component

- For system with basic unit and n stand-by unit

$$R = e^{-\lambda t} + e^{-\lambda t}(\lambda t) + \frac{e^{-\lambda t}(\lambda t)^2}{2!} + \cdots + \frac{e^{-\lambda t}(\lambda t)^n}{n!}$$

- The mean time to failure is

$$\mathrm{MTTF} = \frac{n+1}{\lambda}$$

Reliability engineering

- Concerned with the Techniques in Design, Manufacture and Assurance of the reliability of products.
- Standardization
- Redundancy
- Failure Physics
- Reliability Testing
- Burn in
- Fault Tree Analysis
- Failure Mode and Effect Analysis (FMEA)

Standardization

- Standard components have proven reliability
- Standard components cost less
- Using standard components can reduce down time

Redundancy

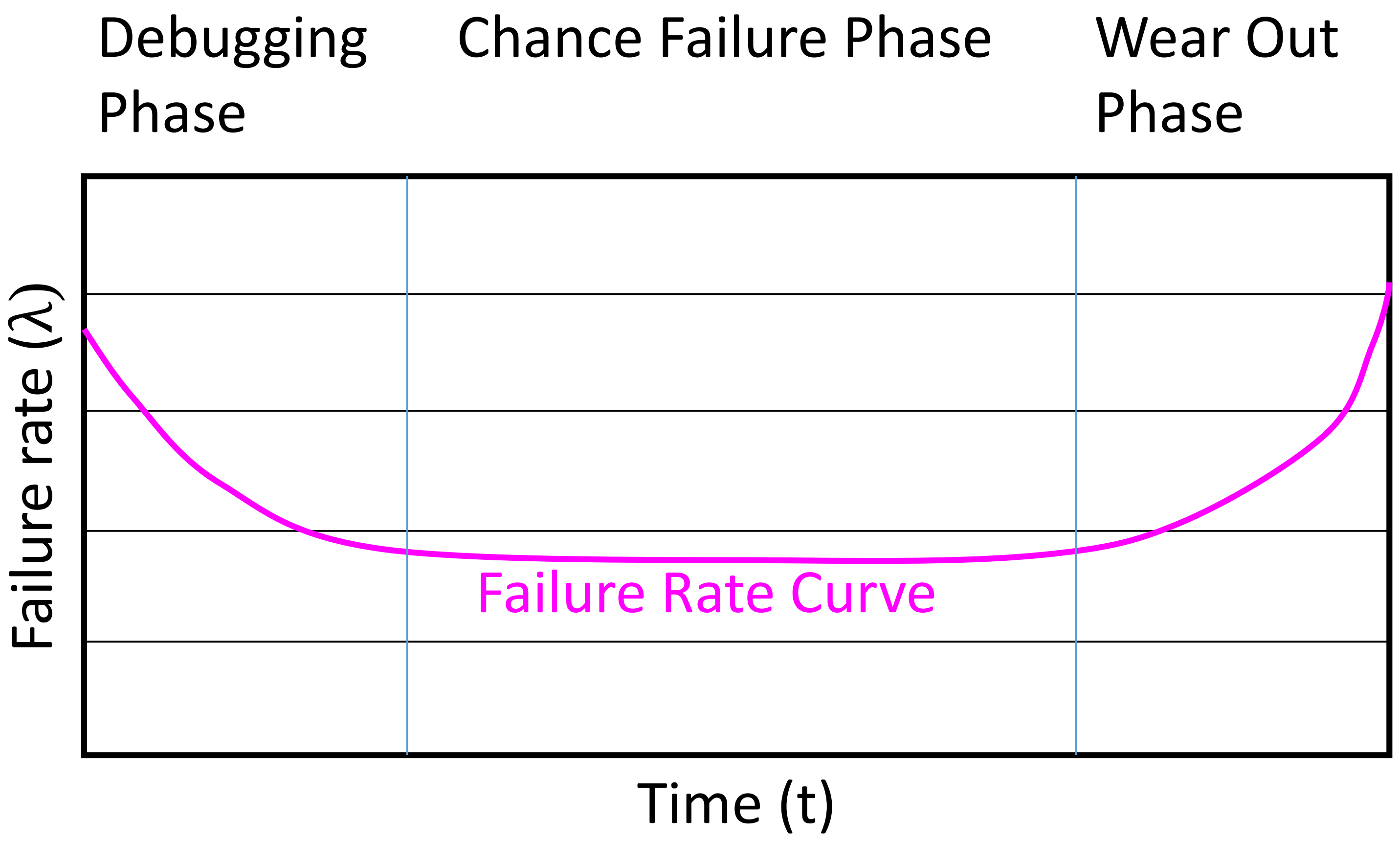
- System with parallel components or stand-by components
- Redundancy provided at the weakest link of the system
- Use in system where failure has extremely costly consequences
- Redundancy increase reliability, but also increase cost

Failure physics

- Study the reasons for product failure

- Identify
- Factor affecting failure
- Failure mechanism
- Involve
  - Physics
  - Chemistry
  - Material Science

Typical failure rate curve



Burn in

- Very High Failure at Early Stage of Usage
- Burn In Covers the Entire Debugging Phase
- Reduce the Number of Weak Components in the product
- Important quality control method in electronic products
- Need cost

Reliability testing

- To collect data on the reliability of a product
- To protect manufacturer from liability
- To evaluate product design
- To evaluate production processes
- To satisfy contract obligations(義務)
- To evaluate warranties

Types of testing

- Life Testing
- Accelerated Life Testing
- Environmental Testing
- Shock and Vibration Testing

- Failure - Terminated Test
- Time - Terminated Test
- Sequential Reliability Test

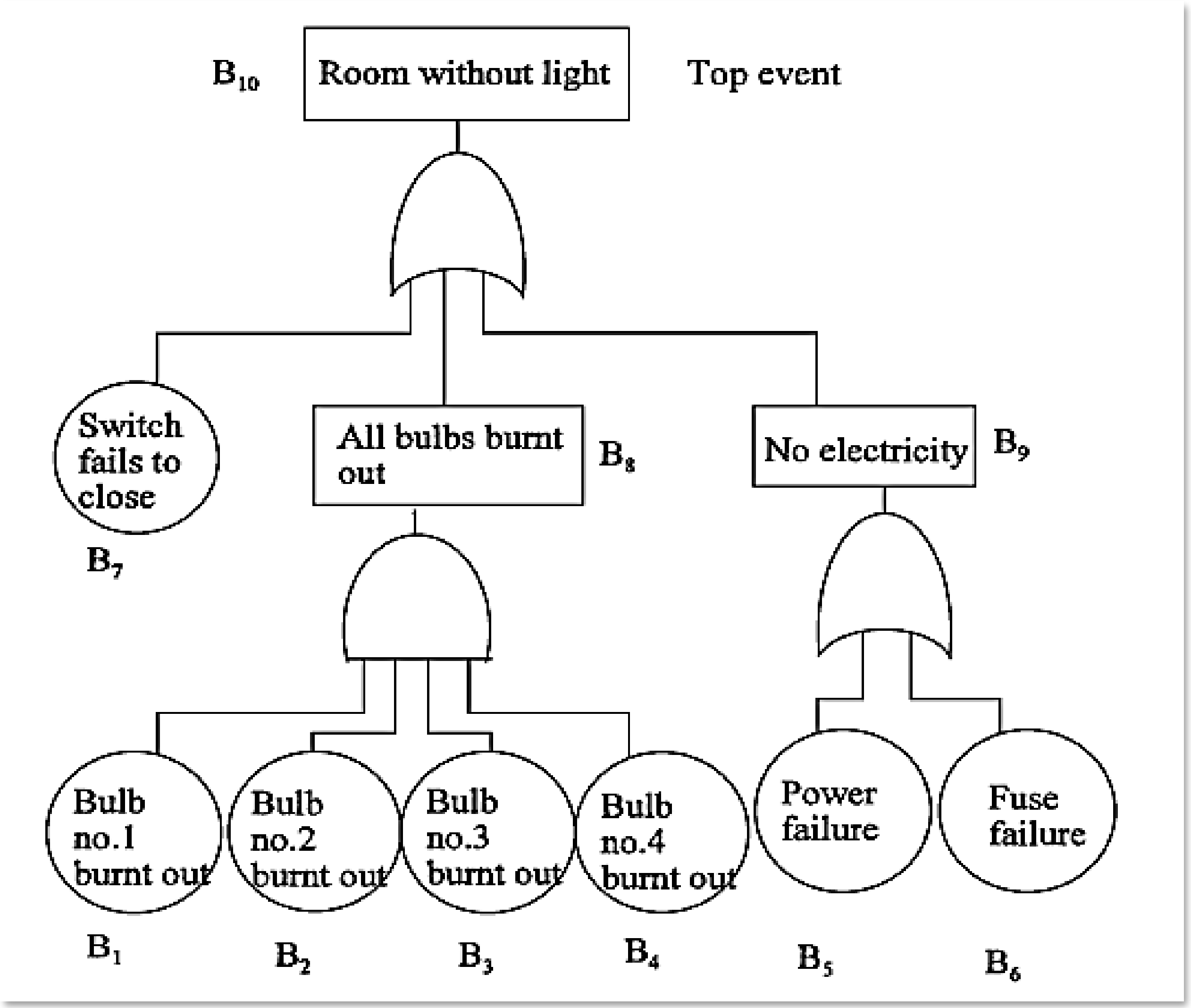
Failure mode and effect analysis (FMEA)

- To identify the different ways by which a product fails
- To find out the consequences if failure occurs
- To find alternative design to minimize failure and its effects

- Components of FMEA
  - Failure Modes
  - Failure Causes
  - Failure Effects
  - Criticality
  - Corrective Actions
  - Remarks

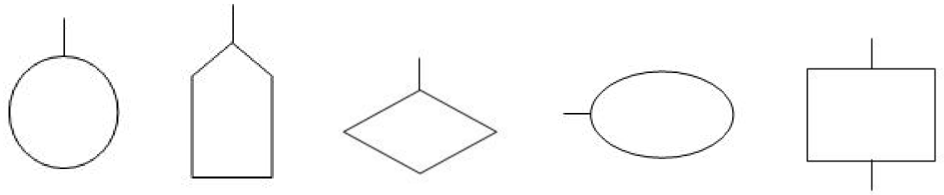
Fault tree analysis

- Fault-tree is used to analyze the cause of failure
- List out the failure of different components and their effects
- Useful in identifying critical components in the system
- Example
- Dark room or room without light



Fault tree symbols

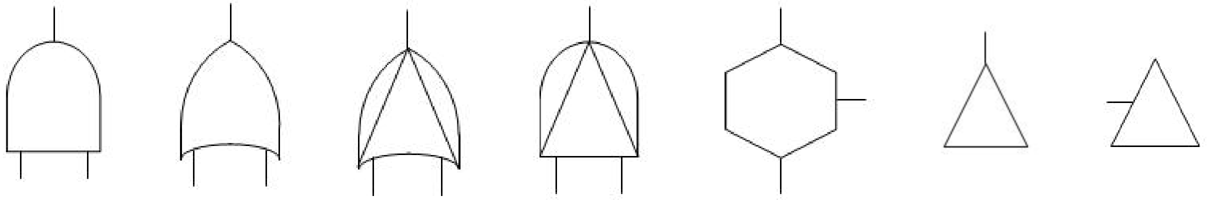
Event Symbols



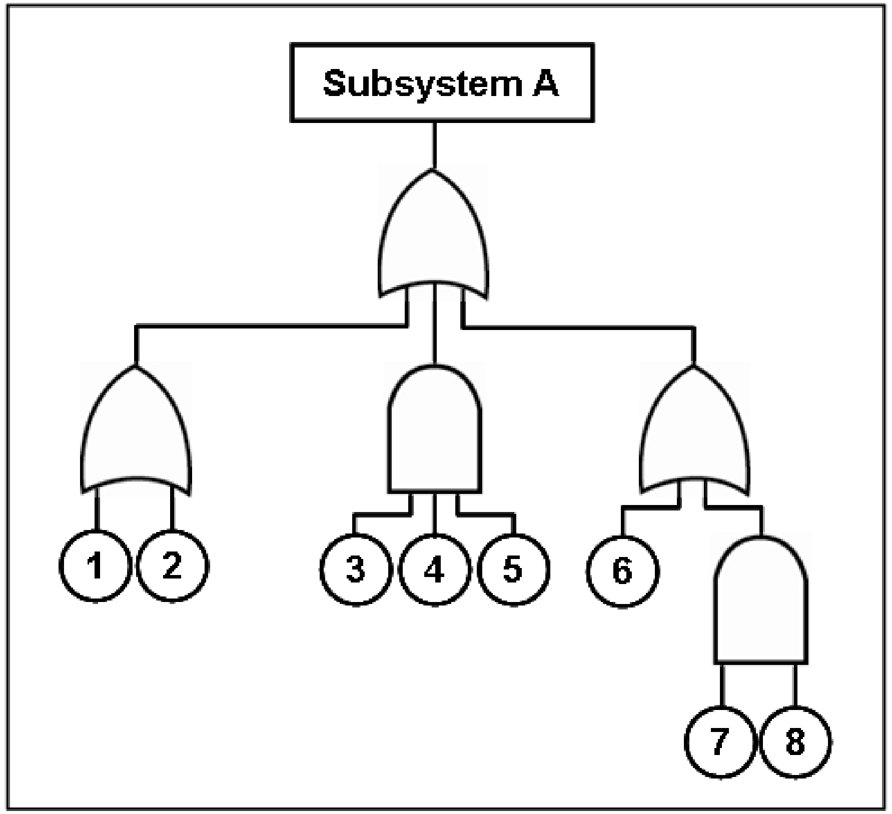
Basic event | External event | Undeveloped event | Conditioning event | Intermediate event

Gate Symbols

Transfer Symbols



OR gate | AND gate | Exclusive OR gate | Priority AND gate | Inhibit gate | Transfer in | Transfer out



Maintainability

- Maintainability is a measure of the ease and rapidity of a system can be restored to operational status following a failure.

- Preventive Maintenance
  - Scheduled Maintenance
  - Reduce Failure Risk

- Corrective Maintenance
  - Repair of Failed Components

1. Parts Easily Accessible
2. Modular Design
3. Standard Components
4. Built-in Diagnostics

Availability

- Availability is the probability that the system is operating satisfactorily at any time.
- Mean down time is the average time the machine is taken out of service during maintenance.
- Mean time between maintenance (MTBM) << Mean time between failure (MTBF).
- Operation Manager can use the operational availability for planning maintenance schedule.

Availability

- Products with good reliability will have a higher availability.
- Products with better maintainability will have a higher availability.
- For example, for a product with 0.99 availability, a product that need 2 hours for repair should have a MTBF of 198 hours or more.

Availability

MTBM - Mean Time Between Maintenance
MDT - Mean Down Time
MTBF - Mean Time Between Failure
MTTR - Mean Time To Repair

- Operational Availability

$$A_0 = \frac{\mathrm{MTBM}}{\mathrm{MTBM} + \mathrm{MDT}}$$

- Inherent(固有) Availability

$$A_t = \frac{\mathrm{MTBF}}{\mathrm{MTBF} + \mathrm{MTTR}}$$